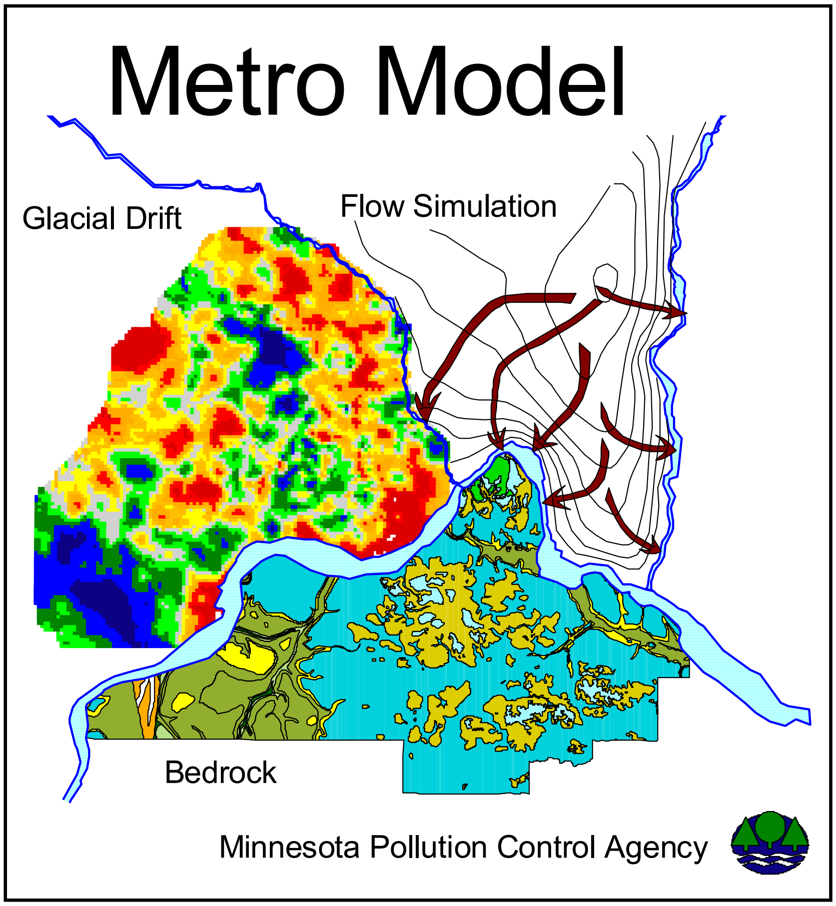
Nomination for 2001 Minnesota Governor's Council on Geographic Information

Twin Cities Metropolitan Groundwater Model (Metro Model)

August 2001



http://www.pca.state.mn.us/water/groundwater/metromodel.html

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Introduction

Staff from the Minnesota Pollution Control Agency (MPCA) have employed the use of Geographic Information Systems (GIS) to develop databases and to construct a computer simulation of regional multi-aquifer groundwater flow in the Twin Cities (Minneapolis and St. Paul, Minnesota) metropolitan area. The GIS-based resources that were developed are available for use in both the public and private sectors. This model, known as the Twin Cities Metropolitan Groundwater Model (Metro Model), simulates regional groundwater flow in the seven-county metropolitan area, covering approximately 7,800 square kilometers (Figure 1).

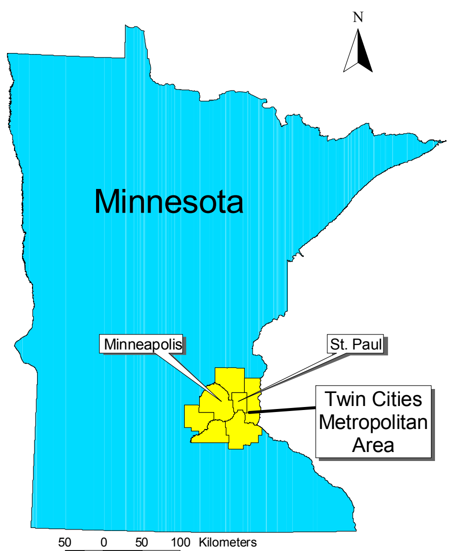


Figure 1. Metro Model Location

A regional view of the metropolitan area displaying the county names and major river valleys is shown in Figure 2.

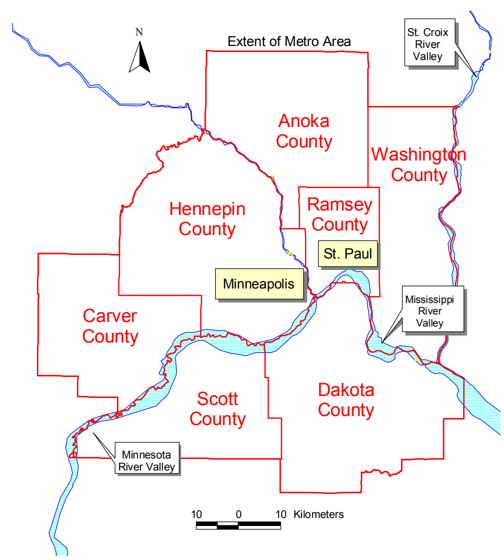


Figure 2. Metropolitan Area Counties

Groundwater scientists working for a wide array of governmental units and private parties use the Metro Model as a groundwater management tool by locally modifying the inputs and inserting site-specific details into the regional backdrop that the Metro Model provides. The Metro Model, and the databases upon which it is based, have become powerful GIS-based technical resources that are in the public domain and are provided free of charge. The standardized datum and coordinate system provided by GIS has allowed Metro Model staff to develop a project that serves as a standardized base upon which groundwater investigation and modeling may proceed, and allows users to produce improved technical products with limited resources.

Because the Metro Model can be used to help satisfy different objectives among the Twin Cities hydrogeologic community, its use ultimately results in better protection of the groundwater resources of the Twin Cities metropolitan area.

The Metro Model adds value to projects by permitting users to develop models in shorter time periods, with lower costs, and almost always with a better technical basis than would otherwise be possible with the same financial resources. This document summarizes the background, development, construction, and application of the Metro Model as a GIS-based groundwater management tool for the Twin Cities metropolitan area. The use and application of Metro Model resources as groundwater management tools are emphasized in this document. Therefore, the description of the development, construction, and operation of the model is brief. More information regarding these aspects can be found in the supporting documentation available from the Metro Model website (URL presented above).

Objective

A technically sound groundwater model represents the aquifer system by including the important physical features that affect flow, and by using hydraulic parameters that reflect the properties of the media. With regional conditions already defined by the Metro Model, the end-user does not need to start building a model from scratch. The Metro Model was developed in a GIS environment to provide a standardized coarse regional context of groundwater flow in the metropolitan area. It can be an effective tool when mindfully modified to include local site-specific conditions. Application of the Metro Model necessarily requires that end-users insert local detail into the model to conduct site-specific modeling.

Background

The Metro Model is a steady-state flow model constructed using the software program Multi-Layer Analytic Element Model (MLAEM) (O.E. Strack, 1992). However, the GIS approach used to develop the databases and the model itself has permitted project resources to be readily applied to other groundwater modeling platforms. Although it has been developed and is maintained by MPCA staff, the model and its supporting databases are being used as management tools by groundwater scientists working in other governmental units, as well as by private companies. MPCA staff apply the resources to problems of groundwater contamination, but they were developed with additional objectives in mind to ensure that they have the broadest utility among all groundwater scientists in the metropolitan area. The Metro Model and its supporting data have been developed to assist planners, government agencies, private consultants, and the people of Minnesota in protecting their groundwater resources

The Minnesota Legislative Commission for Minnesota Resources initially supported the project from its beginning in 1995 through 1999. The US Environmental Protection Agency and the MPCA have provided supplemental funding. Even though work began on the project in 1995, there has been a complete reworking of the Metro Model since the fall of 1998.

End-Users and Peer Review

MPCA staff have spearheaded the Metro Model, but the project really represents a cooperative venture between groundwater scientists in the Twin Cities area from both private and public parties. Its acceptance among the Twin Cities hydrogeologic community is largely attributable to their involvement from the start of the project. The Metro Model team convenes periodic meetings of a group of groundwater scientists and planners called the User Advisory Workgroup. The User Advisory Workgroup represents the actual end-users of the model and its supporting data. They voluntarily provide peer review and feedback to the project team.

Model Construction in a GIS Environment

Conceptual Model and Database

Construction of the Metro Model must be based on a technically sound conceptual model. The conceptual model of regional groundwater flow in turn must be constructed on a solid foundation of data and information. Consequently, Metro Model staff have collected, analyzed, and interpreted a large volume of data in support of the conceptual model. Moreover, these data have been integrated into databases that are readily available to end-users in a GIS-ready format.

The Metro Model team gathers a tremendous volume of information and data from many different sources to develop an understanding of how groundwater flows in the Twin Cities metropolitan area. GIS software is used to graphically present data that include water budget and stream flow discharge rates, bedrock geology, glacial geology, water levels, and flow characteristics of the soils and bedrock. The supporting databases are critical to the integrity of the Metro Model. Therefore, GIS database construction and conceptual model development account for approximately 80 percent of the work effort. The Metro Model team has assembled a centralized repository of valuable information critical to groundwater managers within, and outside of, the metropolitan area. Initially developed for the purpose of model construction, these supporting data comprise a valuable resource in itself that is frequently sufficient to address groundwater management problems without the use of the model. Additionally, improvements in modeling techniques are incorporated into the effort as they are developed, and resources permit, to ensure that the Metro Model provides the best possible technical GIS tool for groundwater management issues.

Model Development

The Metro Model simulates flow in five aquifers separated by aquitards, which may be comprised of both bedrock and glacial drift units (Figure 3). A basic premise behind the model is to provide a vertical distribution of surface infiltration to this aquifer system. Because the groundwater modeling software used to build the Metro Model is most effectively applied by including only actual hydrogeologic features and boundaries, the project team decided early on to integrate the model development with the supporting databases through the extensive use of GIS. Maps and databases were reviewed in GIS to identify important features to be included in the development of the groundwater model.

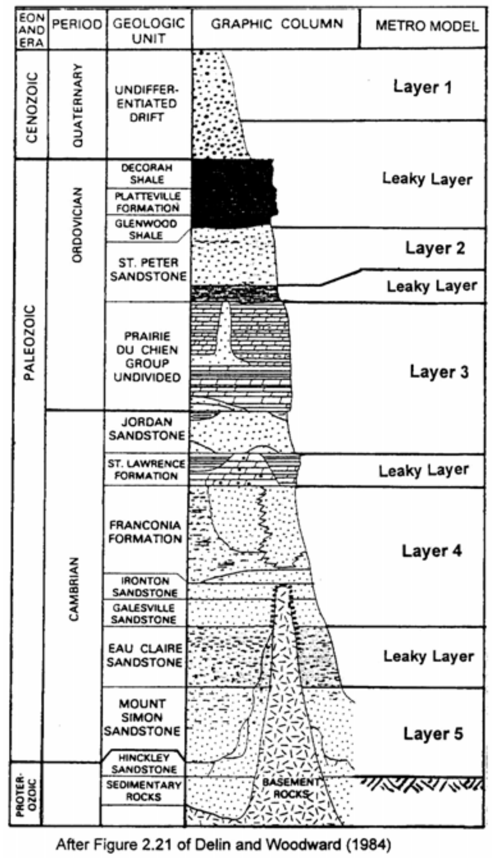


Figure 3. Hydrostratigraphic Column and Conceptual Model

Using GIS software, these features were incorporated into the model as analytic elements, which produce the regional flow of the system. For example, a polygon mesh defines the vertical infiltration distribution and includes major surface waters, as illustrated in Figure 4, which overlays the polygon mesh on top of surface water hydrography. In particular, two large lakes are shown represented by separate polygons. Additionally, hydrologic boundaries imposed by the Mississippi and Minnesota Rivers also help define the polygons.

Changes in bedrock are also used to help construct a polygon mesh, such as the one shown overlaying the bedrock geology map in Figure 5. Many of the polygon sides are defined by, or approximate, the lateral extent of various hydrostratigraphic units, as determined through the use of GIS, indicating differences in vertical leakage throughout the layered system. Other GIS coverages from various sources used in model development include top of the bedrock elevation (Figure 6) and thickness of unconsolidated glacial materials (Figure 7), which was constructed by Metro Model staff. Graphical depictions such as these in a GIS environment are useful to modelers for

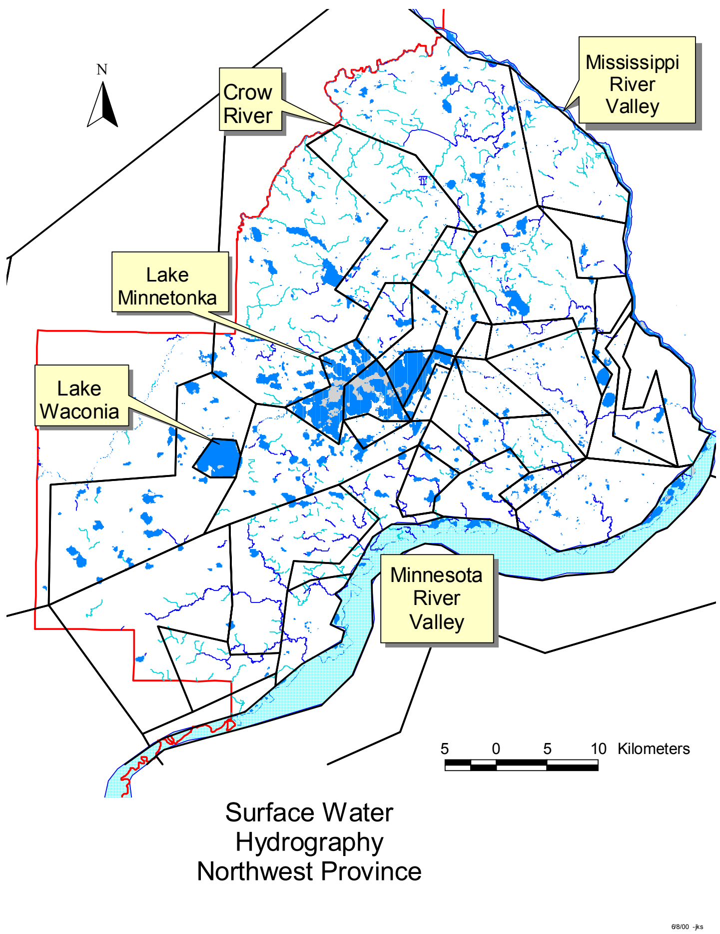
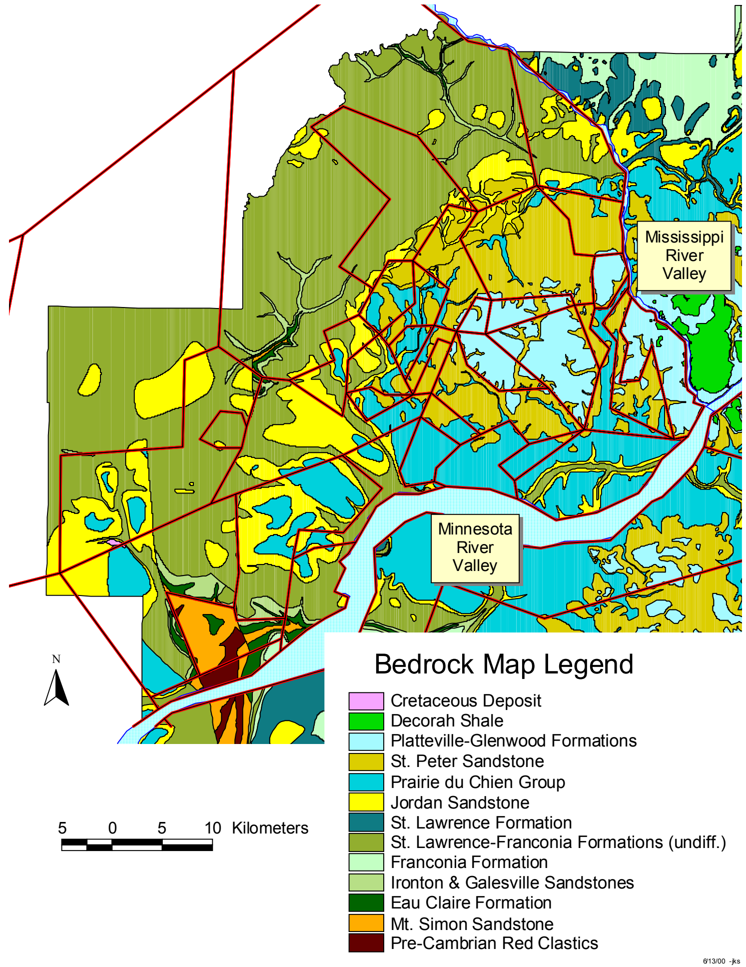


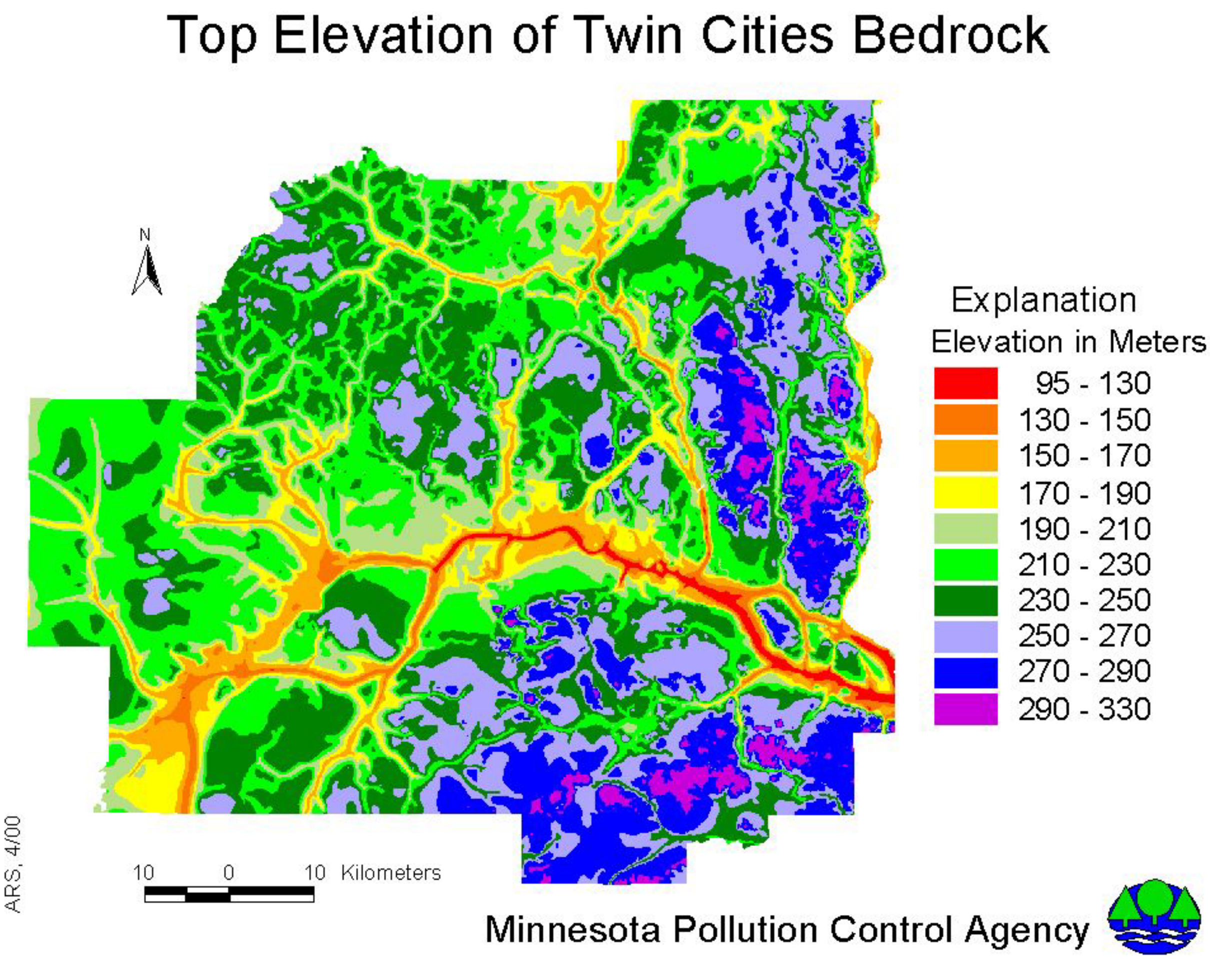
Figure 4. Example of Surface Waters and Polygon Layout



After Mossler and Tipping (2000)

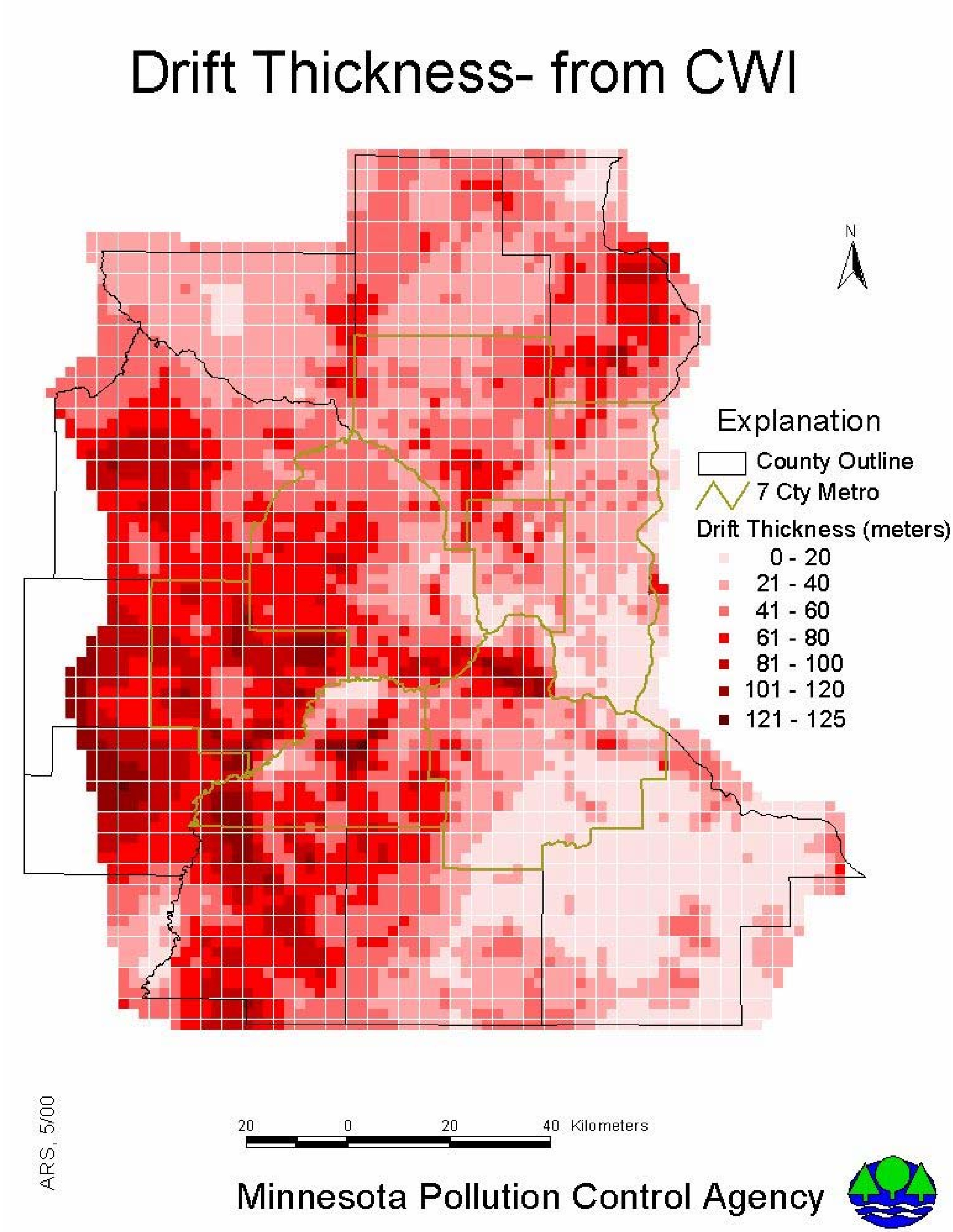
Figure 5. Example of Bedrock Geology and Polygon Layout

defining the geometry of the hydrostratigraphic units. And by providing the supporting GIS defining databases as well as the polygon mesh based on the databases, users can reinterpret the geometry of particular polygons for themselves.



From Streitz (2001), after Mossler and Tipping (2000)

Figure 6. Metropolitan Area Bedrock Topography



From Streitz (2001)

Figure 7. Metropolitan Area Glacial Drift Thickness

Metro Model staff applied and helped advance an innovative approach for defining differences in flow characteristics of the unconsolidated glacial materials aquifer. A statewide database of well log information, known as the Minnesota County Well Index

(CWI), contains a massive amount of well log data of moderate reliability. Metro Model staff subjected the data to automated querying, geostatistical treatment, and filtering, and placed it into a GIS format to produce maps showing gridded sand content for specified elevation horizons throughout the metropolitan area. It was possible to construct a coherent regional picture of the glacial drift hydrogeology because geostatistical methods permitted staff to glean the regional picture from several thousand well logs and present it in GIS. These maps were used to develop the conceptual model and to define inhomogeneities that were constructed in the Layer 1 (glacial drift) models. Figure 8 illustrates the construction of two low-hydraulic conductivity inhomogeneities on the sand content maps for two of the elevation horizons. The warm colors (yellow through red) indicate the higher sand contents, and the colder colors (green through blue) indicate lower sand contents representing tighter materials.

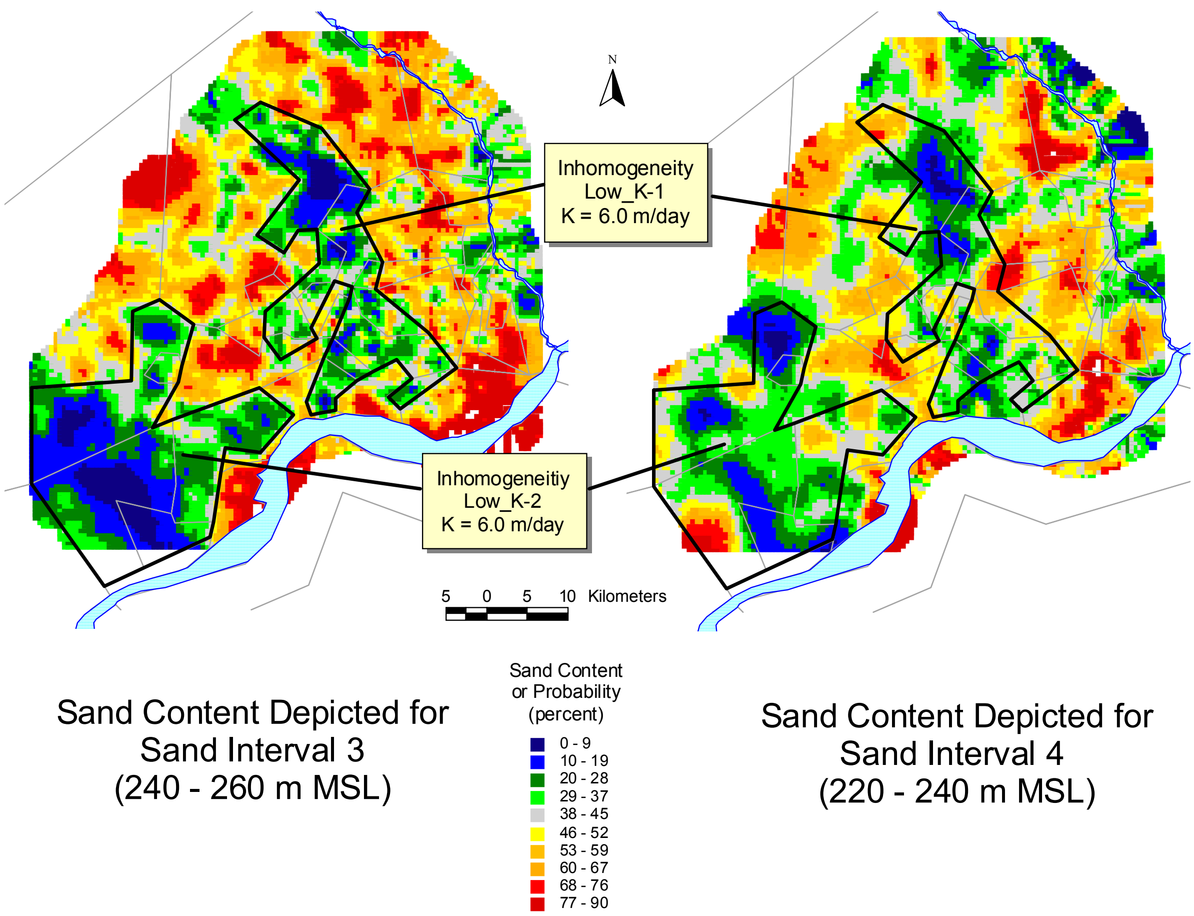


Figure 8. Layer 1 Aquifer Sand Content and Inhomogeneities

GIS coverages illustrating the thickness and upper surface elevations of significant bedrock units were also used in the construction of the Metro Model. These coverages are available to all end-users. Depictions are available with the documentation provided on the Metro Model web site, and the data can be downloaded from the project website or provided on a CD-ROM.

Calibration and Model Results in a GIS Environment

Project staff and end-users alike have found that results of the Metro Model are best evaluated graphically in a GIS environment. Consequentially, GIS is a practical necessity for illustrating modeling results, and is used extensively for their presentation. Figure 9 shows how measured groundwater elevation data are compared to the modeled values on a regional basis by illustrating the difference between modeled and measured groundwater elevations. Plots such as these, developed in GIS, are used to identify trends and clusters where the model deviates from measured conditions. Typical model output is presented in GIS, and includes groundwater elevation plots, such as that presented in Figure 10.

Availability

Metro Model databases, datasets, and documentation have been created as public domain resources and are available to any interested party free of charge. Other larger databases and resources developed for the project are available on a CD-ROM, or can be downloaded from an FTP site on an as-needed basis. However, the vast majority of the resources, including GIS coverages, model datasets, and documentation, are available from the Metro Model website:

http://www.pca.state.mn.us/water/groundwater/metromodel.html

GIS-ready databases and shape files can be readily downloaded from this site by scrolling down to the column titled "Available for Download" and selecting the "Database Files and Maps" hypertext.

Project Benefits

Two aspects of the Metro Model are of particular use to groundwater professionals. First, the supporting databases that have been compiled and interpreted by the Metro Model team supply valuable information in a GIS-ready format for groundwater management decisions. Commonly, information retrieved from Metro Model databases can be used to sufficiently resolve specific groundwater issues. Second, it allows an end-user to construct site-specific models by adding only the necessary local detail, creating a more technically robust model in much less time than would otherwise be possible. The real value of the Metro Model to modeling projects is the ***value added*** to the efforts. Because the local applications are built on a backdrop of the regional hydrogeology, the modeler can spend more time focusing on site-specific features, resulting in a more technically sound model. The Metro Model also provides a standardized GIS-based starting point for groundwater investigations and modeling.

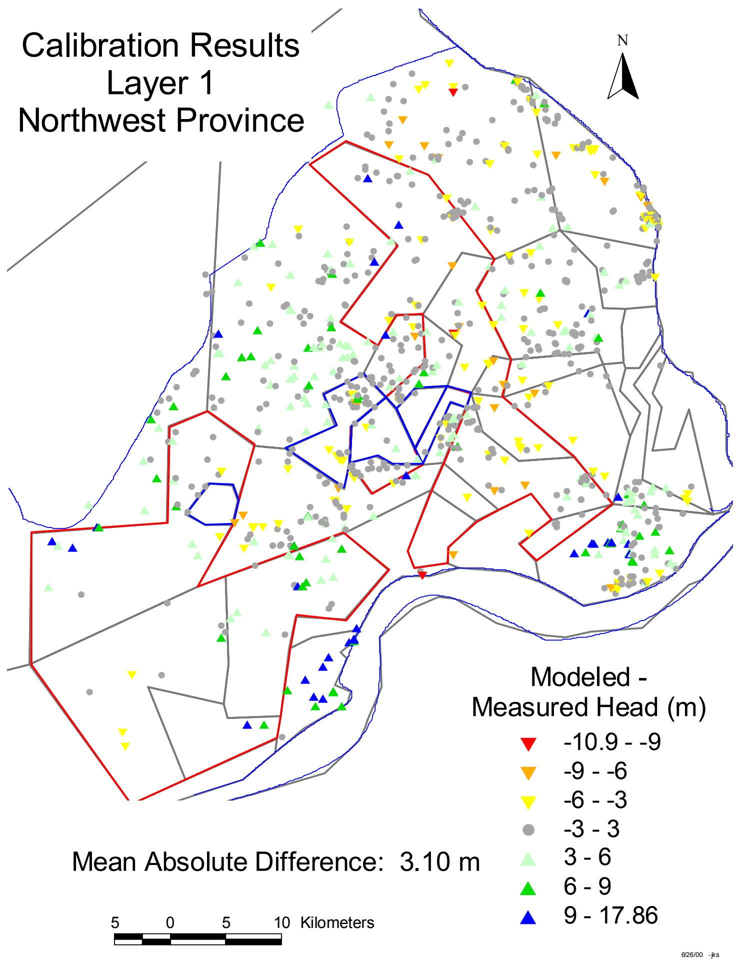


Figure 9. Layer 1 Calibration Plot

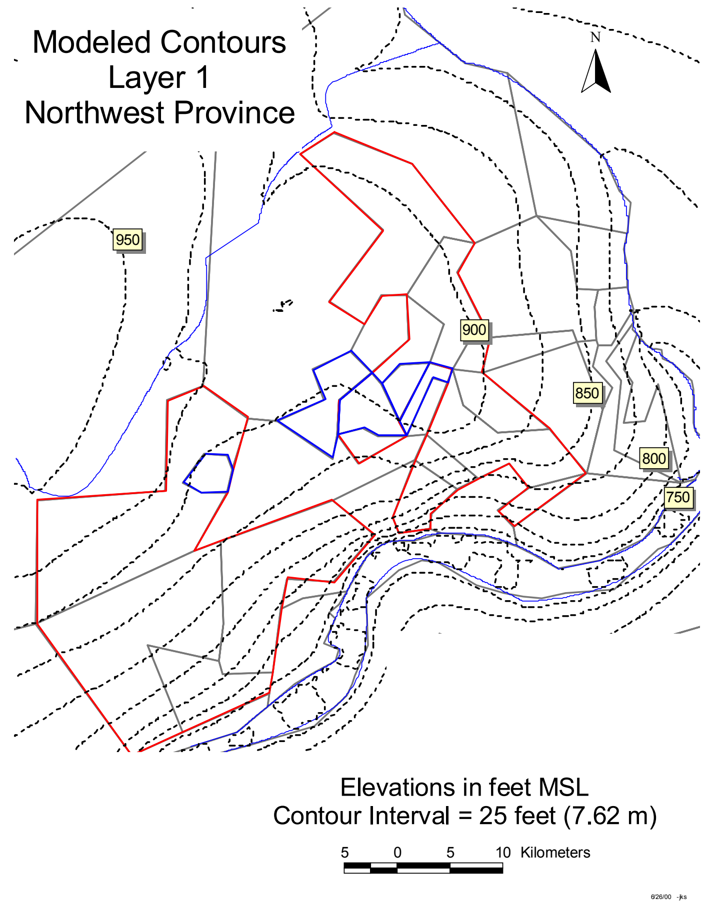


Figure 10. Layer 1 Modeled Groundwater Elevation Contours

Applications

Metro Model resources are regularly being applied by both public and private sector groundwater scientists to solve groundwater management problems. Some examples of these applications from the last three years are included in the list below. Please refer to Figures 2 and 3 for county locations and hydrostratigraphic definition, respectively.

- A consultant to Ramsey County Soil and Water Conservation District used the model and supporting GIS databases as the starting point to develop a countywide multi-layer groundwater model.
- Minnesota Department of Health (MDH) is requiring the use of the Metro Model and its GIS databases as the basis for subregional groundwater flow models for 1) Scott and Dakota Counties; 2) the Prairie du Chien-Jordan aquifer in Washington, Ramsey & southern Anoka counties; 3) the Ironton-Galesville and the Mt. Simon-Hinckley aquifers in Anoka County; and 4) the Anoka Sand Plain Aquifer. Additionally, MDH personnel have used the Metro Model to determine several wellhead delineations in the lower aquifers.
- A consultant to the City of Burnsville (northern Dakota County) used the Metro Model to evaluate the effects of constructing new municipal wells in addition to existing dewatering operations in ecologically sensitive areas.
- In a joint effort involving MDH, Minnesota Department of Natural Resources (MDNR), and MPCA, hydrogeologists from the Twin Cities Metropolitan Council are using the Metro Model to develop a refined model for Dakota and Scott Counties to help evaluate hydrologic impacts of production wells proposed in response to intense development. The sustainability of the groundwater resources will be evaluated, as well as impacts to features such as Boiling Springs, the Savage Fen, and Eagle Creek (trout stream). Additionally, Metropolitan Council personnel will soon apply the Metro Model and its GIS databases to evaluate groundwater sustainability in northwestern Hennepin County.
- A consultant to the Minnehaha Creek Watershed District in Hennepin County applied the Metro Model to evaluate potential effects of dewatering for tunneling operations at the Twin Cities International Airport. A determination of potentially significant drawdown of area lakes has resulted in a revision of construction methods and schedules.
- Consultants evaluating effects from Highway 55 reconstruction on Coldwater Spring used the Metro Model to determine that the activities had the potential to cause significant impacts, resulting in further evaluation of the effects to this resource.
- MDNR personnel applied the Metro Model as a screening tool to evaluate potential hydrologic impacts of two proposed limestone quarries in southern Dakota County.
- A consulting company contracted by South Washington County Watershed District used the Metro Model to analyze surface water/groundwater interactions, and the fate of groundwater at various infiltration sites.

- The GIS-based Metro Model datasets and supporting information have been provided on request to consultants for use in developing local models for groundwater contamination sites.
- The Metro Model is applied to sites overseen by MPCA personnel as a tool for management of contaminated groundwater.
- Other users have included Hennepin County Conservation District, government scientists at the Federal, State, and County level, as well as University researchers, representatives of industry, and private consultants.

Detailed testimonials are provided by some end-users of the Metro Model and its GIS databases in the section containing letters of support included with this nomination. Fourteen of these letters were originally prepared in support of another awards nomination approximately one year ago. In the interest of saving time and money and avoiding duplication of effort, they are included here with the permission of their authors. Three other letters were explicitly written in support of this nomination. Please feel free to contact the authors as references to this project.

Goals Served by the Metro Model Project

The reliance on and promotion of GIS resources allow the Metro Model to satisfy almost all the goals of the Governor's Council on GIS in terms of data and information regarding geology and groundwater in the Twin Cities metropolitan area. Commonly, use of the Metro Model and its databases represents the first-time introduction of an end-user to using GIS. The goal best served by the project is the efficient investment in geographic information. The initial investment in the project has permitted staff to produce a GIS-based resource that serves many different objectives for the broad hydrogeologic community, including both public and private sectors. Ready availability through our web-site does not allow us to account for all the applications of the project, but personal testimonials and web-site statistics indicate that the project is viewed and used as a significant resource for the hydrogeologic community.

Nominee

The Minnesota Pollution Control Agency is being nominated to receive this award.

Summary

The Metro Model project signifies a unique approach in applying GIS to protecting groundwater resources. Model development and output occur in a standardized GIS environment. The project relies on and promotes the cooperative spirit of Twin Cities metropolitan area groundwater professionals in both the public and private sectors. Project staff have pooled and leveraged the resources from these cooperative parties to develop and construct a regional context of groundwater flow that forms a standardized starting point upon which studies and models can be based. The actual flow models that comprise the Metro Model are built on a foundation of information and data from many different sources. Project data and flow models deliberately reflect regional groundwater conditions. Application of these resources generally requires the addition of local site-specific data.

A broad range of objectives for Metro Model GIS resources naturally results from the diversity of interested parties. However, project peer review, which relies heavily on the incorporation of the feedback and input from the interested parties, has resulted in overall acceptance of project GIS databases and models as technically sound tools for management of groundwater resources. The project has evolved from the development phase into a resource that has made a significant contribution to the protection and use of groundwater resources in the Twin Cities metropolitan area.

Project resources for the Metro Model are GIS-based and in the public domain, and are made available free of charge. Access to supporting databases, model datasets, and documentation relies heavily on the project website. Larger project resource files are available on CD-ROM, and data and files are also distributed over the Internet via FTP on an as-needed basis.

The Metro Model project provides databases, information, model datasets, and documentation. The GIS approach taken by the team has resulted in flexibility that permits project datasets to be applied by different modeling software programs. Actual applications of the Metro Model and its supporting GIS databases by various parties have demonstrated that mindful application of Metro Model resources can save time and money while providing a more technically robust product than would have otherwise been possible.

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